MINIMALLY INVASIVE THERMAL THERAPY FOR CANCER TREATMENT BY USING THIN COAXIAL ANTENNAS

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Abstract - **In recent years, various types of applications of electromagnetic techniques for microwave thermal therapy have been developed. Among them, minimally invasive microwave thermal therapies for cancer are of great interest. They are interstitial microwave hyperthermia and microwave coagulation therapy. In this paper, we describe the characteristics of thin coaxial antennas for those therapies.**
Keywords **- Minimally invasive microwave thermal therapy, hyperthermia, microwave coagulation therapy, thin coaxial antenna**

I. INTRODUCTION

In recent few decades, various types of medical applications of microwaves have widely been investigated and reported [1]. In particular, minimally invasive microwave thermal therapies using thin applicators are of great interest. They are interstitial microwave hyperthermia [2] and microwave coagulation therapy (MCT) for medical treatment of cancer [3], cardiac catheter ablation for ventricular arrhythmia treatment [4], and so on.

The authors have been studying thin coaxial antennas for the interstitial microwave hyperthermia and the MCT. In this paper, first, we describe the heating characteristics of the antennas for the interstitial microwave hyperthermia, particularly, in the case of combining the hyperthermia and the interstitial radiation therapy. Next, we show the modality of the MCT and some problems of conventional antennas. Moreover, we introduce a new type of antenna for the MCT to solve one of the problems.

II. INTERSTITIAL MICROWAVE HYPERTHERMIA

A. Interstitial Microwave Hyperthermia and Interstitial Radiation Therapy

Hyperthermia is one of the modalities for cancer treatment, utilizing the difference of the thermal sensitivity between tumor and normal tissue. In this treatment, the tumor or target cancer cell is heated up to the therapeutic temperature between 42 and 45 ^{o}C without overheating surrounding normal tissues. Particularly, combination of the interstitial hyperthermia and the interstitial radiation therapy is effective for treatment of radiation resistive tumor [2]. Figure 1 shows the treatment system of the combined therapy. This treatment system is realized by using the same catheters between the interstitial hyperthermia and the interstitial radiation therapy. In this system, firstly, thin microwave antennas such as the coaxial-slot antenna [5] with catheter heat the tumor. After heating, only the antennas are pulled out of the catheters. Then, radiation sources such as the iridium 192 are automatically inserted into the catheters by a "high dose rate afterloading system".

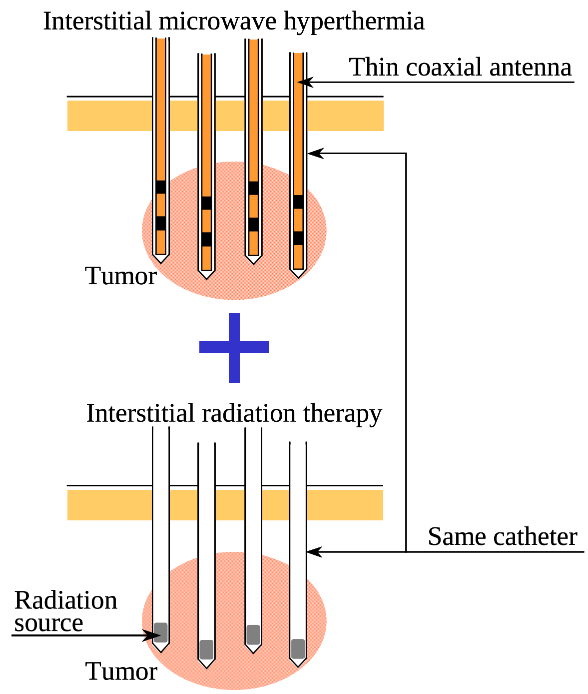

Fig. 1. Combined therapy.

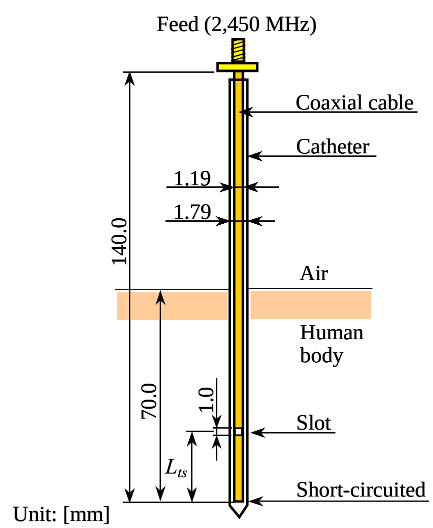

Fig. 2. Basic structure of the coaxial-slot antenna.

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Abstract

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B. Heating Characteristics of the Coaxial-Slot Antennas for the Combined Therapy

The authors have studied the coaxial-slot antennas for the interstitial heating. Figure 2 shows the basic configuration of the coaxial-slot antenna. This antenna is composed of thin semirigid coaxial cable. A ring slot is cut on the outer conductor of a thin coaxial cable and the tip of the cable is short-circuited. L_{ts} is the length from the tip to the center of the slot. The operating frequency is 2,450 MHz that is the one of the ISM (Industrial, Scientific, and Medical) frequencies.

In order to obtain the large heating region, we use the array applicator, which is composed of some antennas. Therefore, we employed the array applicator composed of four coaxial-slot antennas. In this paper, we analyze the heating characteristics of the array applicator by the numerical simulation.

First, we calculate the SAR (specific absorption rate) distribution around the antenna from

$$\mathrm{SAR} = \frac{\sigma}{\rho} E^2 \qquad \text{[W/kg]} \tag{1}$$

where σ is the conductivity of the tissue [S/m], ρ is the density of the tissue [kg/m^3], and E is the electric field (rms) [V/m]. The SAR takes a value proportional to the square of the electric field around the antennas and is equivalent to the heating source generated by the electric field in the tissue. The SAR distribution is one of the most important characteristics of the antennas for the heating. Figure 3 (a) shows the calculated SAR distribution of the array applicator composed of four coaxial-slot antennas, which is inserted into a muscle (ε_r =47.0, σ =2.21 S/m at 2,450 MHz). Here, Fig. 3 (b) shows the SAR observation plane. In this calculation, L_{ts} and the array space A_s were set to 5 mm and 15 mm, respectively. From Fig. 3 (a), we can observe the high SAR regions exist not only near each antenna but also at center of the array applicator. The high SAR regions at the center of the array applicator are caused by the mutual coupling between each antenna element.

TABLE I
PARAMETERS FOR TEMPERATURE CALCULATION.

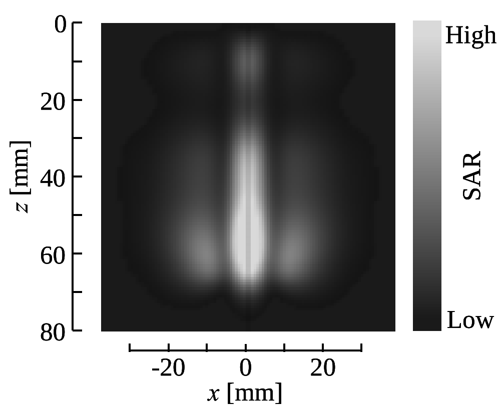
Muscle	
Specific heart c [J/kg·K]	3,500
Thermal conductivity κ [W/m·K]	0.60
Density ρ [kg/m^3]	1,020
Blood	
Specific heart c_b [J/kg·K]	3,960
Density ρ_b [kg/m^3]	1,060
Blood flow rate F [m^3/kg·s]	8.33×10^{-6}
Temperature of the blood T_b [^{o}C]	37.0
Others	
Initial temperature [^{o}C]	37.0
Heating time [s]	600
Net input power (total of the array) [W]	12.0

Next, we calculate the temperature distribution around the array applicator. In order to obtain the temperature distribution in the tissue, we numerically analyze the bioheat transfer equation [6] including the obtained SAR values by using the FEM (finite element method). The bioheat transfer equation is given by

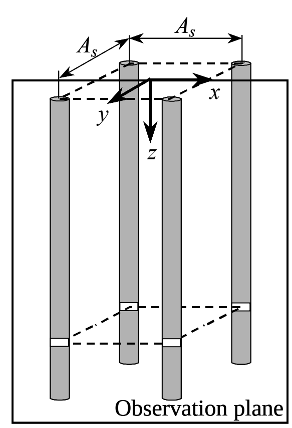
$$\rho\, c \frac{\partial T}{\partial t} = \kappa \nabla^2 T - \rho\, \rho_b\, c_b\, F\left(T - T_b\right) + \rho \cdot \mathrm{SAR} \tag{2}$$

where T is the temperature [^{o}C], t is the time [s], ρ is the density [kg/m^3], c is the specific heat [J/kg·K], κ is the thermal conductivity [W/m·K], ρ_b is the density of the blood [kg/m^3], c_b is the specific heat of the blood [J/kg·K], T_b is the temperature of the blood [^{o}C], and F is the blood flow rate [m^3/kg·s].

Figure 4 shows the temperature distributions around the array applicator composed of four coaxial-slot antennas. Here, the temperature observation plane is the same as Fig. 3 (b). The parameters of the temperature calculation are listed in Table I. From this figure, we can observe a large and uniform heating region though the result of the SAR distribution, which is shown in Fig. 3 (a), is not uniform. This result clearly shows that the array applicator is useful for developing the treatment system combining the interstitial microwave hyperthermia and the interstitial radiation therapy.



(a) SAR distribution.



(b) Observation plane.

Fig. 3. SAR distribution of the array applicator composed of four coaxial-slot antennas.

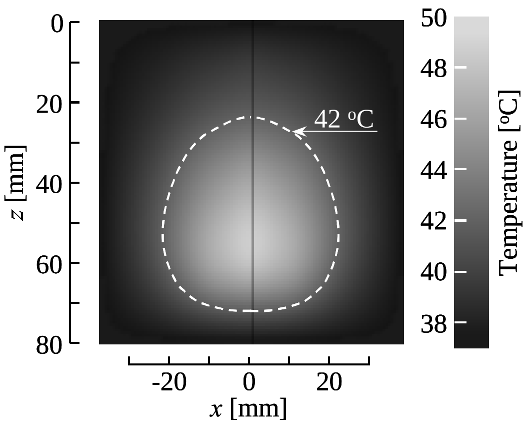


Fig. 4. Temperature distribution of the array applicator composed of four coaxial-slot antennas.

III. Microwave Coagulation Therapy

A. Scheme of the MCT

The MCT has been used mainly for the treatment of hepatocellular carcinoma. Figure 5 shows the scheme of the MCT. In the treatment, thin microwave antenna is inserted into the tumor and the microwave energy heats up the tumor to produce the coagulated region including the cancer cells. We have to heat the cancer cells up to at least 60 °C above which the cells are coagulated. At present, there are some problems to be improved for the conventional MCT antennas. Particularly, there is a problem that length of the coagulated region becomes long in the antenna insertion direction. In this paper, we employed the coaxial-dipole antenna [7], [8] to solve this problem.

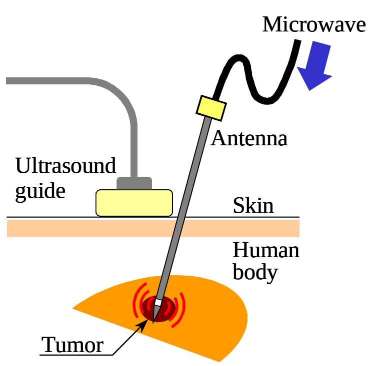


Fig. 5. Scheme of the MCT.

B. Coaxial-Dipole Antenna

Figure 6 shows the structure of the coaxial-dipole antenna. This antenna corresponds to the coaxial-slot antenna united with two conductive sleeves. The sleeves are connected on the both side of the slot. In this time, the length of the sleeves was set to 20 mm.

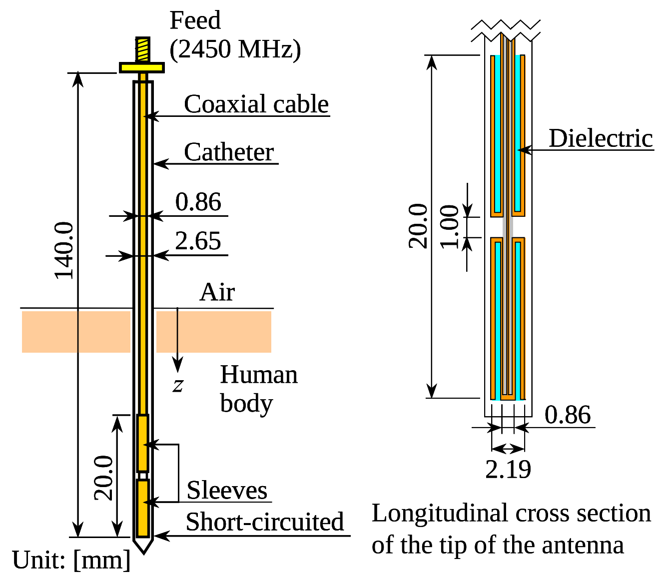


Fig. 6 Basic structure of the coaxial-dipole antenna.

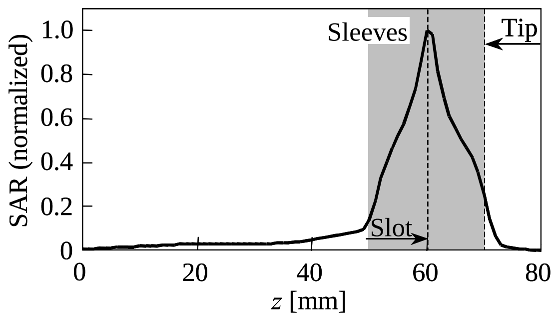
C. FDTD Calculations

We investigated the SAR distribution of the coaxial-dipole antenna by using the FDTD method. Figure 7 (a) shows the normalized SAR distributions of the coaxial-dipole antenna. In addition, the SAR distribution around the coaxial-slot antenna is also presented in Fig. 7 (b) for comparison (the L_{ts} of the antenna is 10 mm). From the result, we can observe the well-localized SAR profile at the tip of the coaxial-dipole antenna in comparison with that of the coaxial-slot antenna.

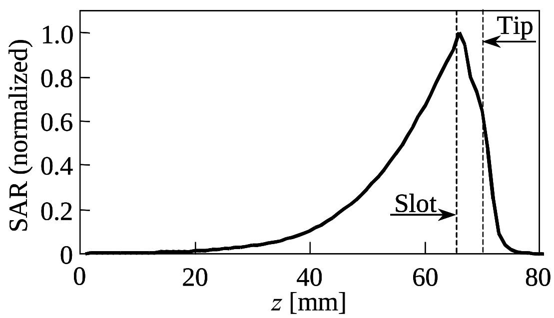
In order to understand the mechanism of generating the localized heating by the coaxial-dipole antenna, the current distribution on the antenna is calculated. Figure 8 shows the current distributions on the antenna. Figure 8 (a) and (b) show the current distribution on the coaxial-dipole antenna and the coaxial-slot antenna, respectively. In the FDTD calculation, the current distribution is defined as the strength of magnetic field in the orthogonal direction to the antenna axis. From Fig. 8, in the coaxial-dipole antenna, a localized distribution appears around the sleeves, compared with the current distribution on the coaxial-slot antenna. The localized current distribution generates the localized SAR distributions around the sleeves.

IV. Conclusion

In this paper, we described the characteristics of the thin coaxial antennas for the minimally invasive microwave thermal therapies for cancer. First, we showed the heating characteristics of the array applicator for the interstitial microwave hyperthermia combined with the interstitial radiation therapy. Next, we explained the scheme of the MCT, and introduced a solution for the problem of the conventional antenna. As a further study, we are going to reveal the effectiveness of the antennas by conducting the animal experiments.

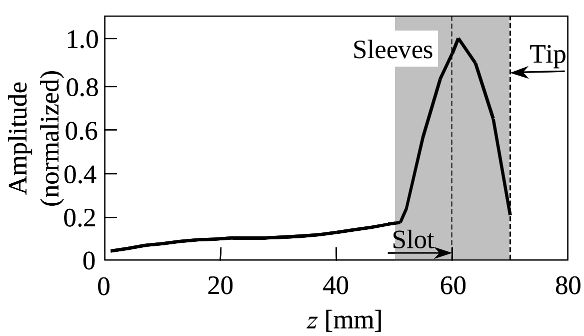


(a) Coaxial-dipole antenna.

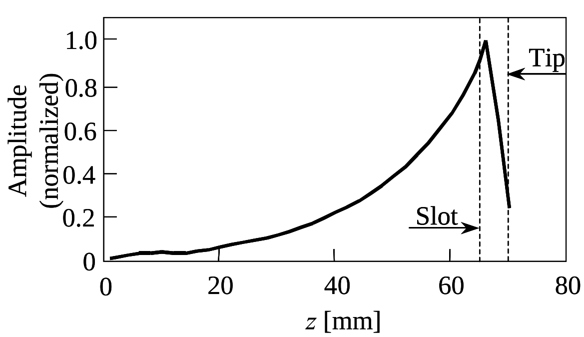


(b) Coaxial-slot antenna.

Fig. 7. SAR distributions.
The observation line is the line of the longitudinal direction of the antenna at the distance of 3.0 mm away from the antenna axis.



(a) Coaxial-dipole antenna.



(b) Coaxial-slot antenna.

Fig. 8. Current distributions on the antenna.

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REFERENCES

[1] K. Ito, “Medical applications of microwave,” *Proc. APMC’96*, vol. 1, pp. 257-260, December 1996.

[2] M. H. Seegenschmiedt, P. Fessenden, and C. C. Vernon, eds., *Thermoradiotherapy and Thermochemotherapy*, vol. 1, Berlin: Springer-Verlag, 1995.

[3] T. Seki, M. Wakabayashi, T. Nakagawa, T. Itoh, T. Shiro, K. Kunieda, M. Sato, S. Uchiyama, and K. Inoue, “Ultrasonically guided percutaneous microwave coagulation therapy for small carcinoma,” *Cancer*, vol. 74, pp. 817-825, August 1994.

[4] S. Labonté, A. Blais, S. R. Legault, H. O. Ali, and L. Roy, “Monopole antennas for microwave catheter ablation,” *IEEE Trans. Microwave Theory Tech.*, vol. 44, no. 10, pp. 1832-1840, October 1996.

[5] K. Ito, K. Ueno, M. Hyodo, and K. Kasai, “Interstitial applicator composed of coaxial ring slots for microwave hyperthermia,” *Proc. 1989 ISAP*, vol. 2, pp. 253-256, August 1989.

[6] H. H. Pennes, “Analysis of tissue and arterial blood temperatures in the resting human forearm,” *J. AppL. Phys.*, vol. 1, pp. 93-122, 1948.

[7] K. Iwata, K. Udagawa, M. S. Wu, K. Ito, and H. Kasai, “A basic study of coaxial-dipole applicator for microwave interstitial hyperthermia,” *Proc. 12th Annu. Meeting of the Japanese Society of Hyperthermic Oncol.*, pp. 230-231, September 1995.

[8] K. Saito, S. Hosaka, T. Taniguchi, H. Yoshimura, and K. Ito, “Improvement of heating patterns by using a coaxial-dipole antenna for microwave coagulation therapy,” *Dig. USNC/URSI National Radio Science Meeting 2000*, p. 157, July 2000.